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Fiber Bragg Grating Metrology Round Robin: Telecom Group

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Abstract
We briefly discuss the measurement of center wavelength, bandwidth, minimum transmittance, and relative group delay ripple from a fiber Bragg grating round robin among a group of telecom companies. We find that the state of fiber Bragg grating metrology in industry, needs improvement in most areas (transmittance, reflectance, wavelength, and relative group delay). Source amplified spontaneous emission can be a limiting effect in the minimum transmittance measurements, and wavelength accuracy and step size are critical for measurement of bandwidth and relative group delay ripple.

1. Introduction

In this paper we report on some of the results from a fiber Bragg grating (FBG) round robin conducted by NIST. FBGs are extremely important for telecommunication and sensor applications. In new wavelength-division multiplexed (WDM) optical-fiber communication systems, FBGs are used as wavelength filters and dispersion compensators. Also, FBGs make excellent strain sensors that can be networked to obtain distributed strain measurements of large structures, such as bridges and ships. In spite of the numerous and growing commercial applications of FBGs, there are no standard measurement procedures, and a variety of definitions are being used for important parameters.

Two parallel round robins were organized to assist industry in evaluating FBGs for telecommunication and sensor applications. The round robin participants in the two groups were, ADC, Agilent, Corning, Perkin Elmer, GNnet-test, NPL, and 3M in the telecom group, and Blue Road Research, CiDRA, EXFO, Micron Optics, NRL in the sensors group. Because no formal methods for analyzing the spectral or relative group delay (RGD) data existed only raw data, from the participants, were sent to NIST. In this paper we discuss only selected measurements from the telecom group on the center wavelength, bandwidth, and transmittance of a FBG at 1552.526 nm (corresponding to the International Telecommunication Union (ITU) channel 0) with a 50 GHz bandwidth. Also from the telecom group, we discuss the RGD measurements on a chirped FBG that was 16 nm wide.

2. Measurement Techniques

Measurement techniques varied among the participants. The telecom group used primarily a grating-tuned diode laser, power meter, and wavelength meter system for spectral measurements. The system used by NIST to make spectral measurements is shown in Fig. 1. A tunable fiber Fabry-Perot (FFP) filter was used to filter amplified spontaneous emission (ASE) from a grating-tuned diode laser. A wavelength meter provided the wavelength scale to an uncertainty of 0.2 pm. The detectors and lock-in amplifiers are linear to within 1% over the 60 dB measurement range. However, only relative reflectance and transmittance data are reported because losses in each of the participant's measurement systems are not known. Source power fluctuations are removed by monitoring the power at the second coupler port. The coupler splitting ratio has a weak wavelength dependence of about 0.01 dB/nm over the 1540 to 1560 nm range.

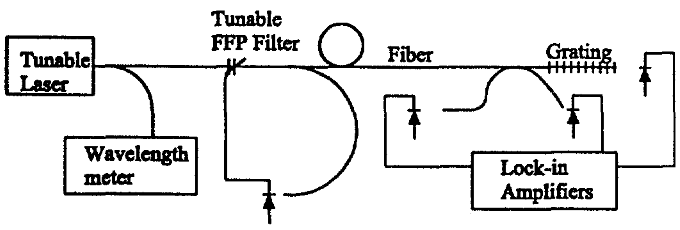

Figure 1 A schematic of NIST's spectral measurement system.

The effect of the tunable FFP filter on the laser can be seen in Figs. 2 and 3. Fig. 2 shows the unfiltered and filtered output of the tunable laser over the 1350 to 1650 nm band. These data were taken with a, 1 nm resolution, optical spectrum analyzer. The laser peak power at 1553 nm was about 308 μW and the integrated ASE across the measured spectra in Fig. 2 was about 1.7 μW. The ratio of these powers is about 23 dB and is a good measure of the dynamic range of the system without the tunable FFP filter. With the FFP filter the ASE is suppressed so that the transmitted laser power is about 174 μW and the integrated ASE power is about 76 pW, for a power ratio of about 64 dB.

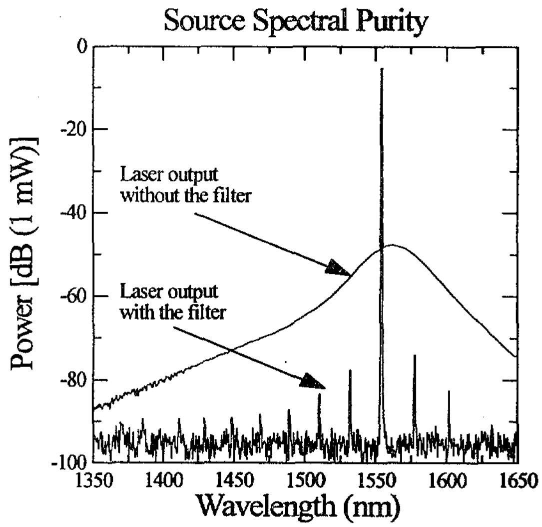

Figure 2 ASE from a tunable laser diode with and without a tunable FFP filter.

Fig. 3 shows the effect of the ASE on a measurement of a FBG's relative transmittance. Without the FFP filter the minimum relative transmittance is only about -25 dB. With the FFP filter the minimum relative transmittance is about -65 dB.

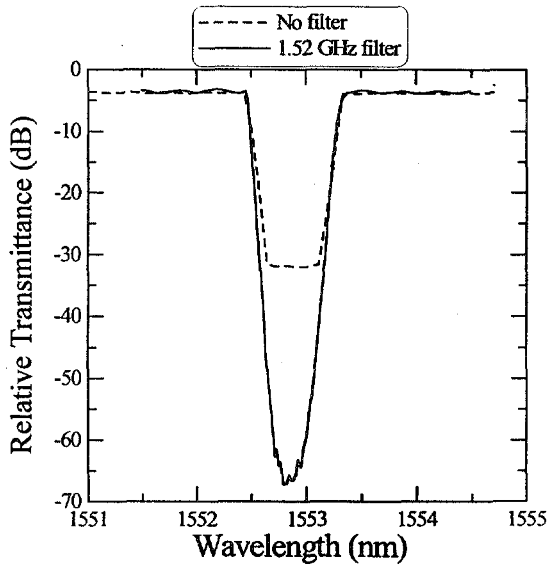

Figure 3 The effect of ASE on the measurement of transmittance in a FBG.

The RGD of the chirped FBG was determined by various rf-phase-shift techniques. A detailed description of the NIST system can be found in reference [1]. The repeatability (2σ) for NIST measurements on the RGD linear slope using the phase-shift system is about 0.25 ps/nm, which could be improved by reducing drift in the rf-modulator. NIST also employed a new low-coherence interferometer method to determine the RGD of the chirped grating. Details of this system are described in the literature [2, 3]. The low-coherence system has a RGD linear slope repeatability of about 0.02 ps/nm.

3. Analysis Methods

To determine the center wavelength and bandwidth of a grating from the reflectance data, NIST used the following methods. First, the maximum reflectance in the plateau region is determined. Then, wavelengths at reflectance values of -3 dB and -0.5 dB from the maximum plateau reflectance were found by interpolating between data. The center wavelength λ_c is defined as $(\lambda_+ - \lambda_-)/2$, and the bandwidth is defined as $c/(\lambda_+ - \lambda_-)$, where $\lambda_{+/-}$ are the wavelengths at data values -x dB (x = -0.5 or 3) on each side of the plateau region, and c is the speed of light. The minimum relative transmittance is determined from relative transmittance data by fitting a spline function to the data and locating the minimum. From the RGD data, the linear slope of the chirped grating is determined using a least squares fit from data within the -3 dB reflectance bandwidth. The residual RGD is found by subtracting the linear slope from the RGD reflectance data.

4. Round Robin Results

Both FBGs -3 dB center wavelength was monitored throughout the round robin to correct for any changes that might occur due to shipping damage or thermal shock. The ITU and chirped gratings did show measurable changes, 37 pm for the ITU, and 75 pm for the chirped, and were attributed to a mechanical shock that damaged other fibers in the grating box. Appropriate corrections were added to each participant's data. The gratings were place on a thermal-electric cooler and athermally packaged so temperature variations from lab to lab would not affect the FBG center wavelength.

The measurements of the minimum relative transmittance of the ITU grating, taken from the relative transmittance data showed the participants measuring about a 23 dB minimum; NIST measured a 27.5 dB minimum. As discussed earlier, for strong gratings, the minimum relative transmittance measurement is quite sensitive to the spectral purity of the laser light source. NIST's FFP filtered laser shows the lowest minimum transmittance, an indication that the participants probably had some amount of ASE in their measurement systems.

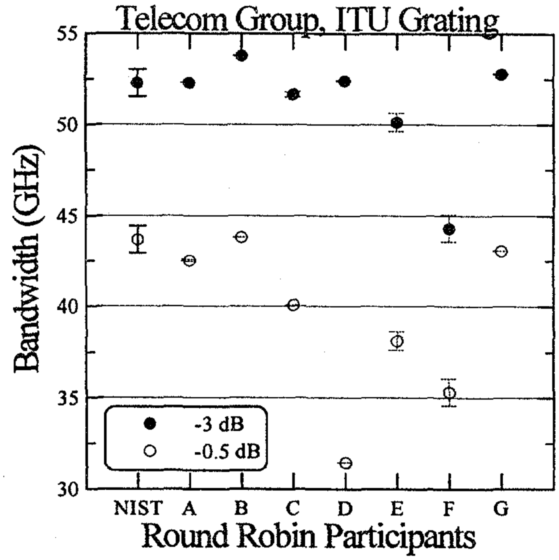

Figure 4 Bandwidth of the ITU grating using two band-edge criteria. Participant's error bars are only the fit uncertainty.

The ITU grating λ_c determined from the round robin reflectance data sets with a -3 dB criterion had a 27.5 pm range of values, with a standard deviation σ of 8 pm and a mean of 1552.521 nm. With a -0.5 dB criterion the λ_c values had a 42 pm range, with a σ of about 12 pm and a mean of about 1552.515 nm. Thus, no significant change in λ_c was found between the -0.5 and -3 dB criteria and the σ for each λ_c evaluation is adequate for WDM applications at present, but may need to be improved as system requirements increase.

Fig. 4 shows the results of the ITU grating bandwidth determined with the -3 dB and -0.5 dB band-edge criteria. The error bars for NIST uncertainty are 748 MHz while the participants error bars are just the fit uncertainty. For the -3 dB criterion, the mean bandwidth is 51.2 GHz with a range of 9.5 GHz and a σ of 3 GHz. In most cases the participants would pass this as a 50 GHz ITU grating using the -3 dB criterion [4].

For the -0.5 dB criterion the mean is about 39.7 GHz with a range of about 12 GHz and a σ of about 4 GHz. In some cases, where the bandwidth must fill the full channel spacing, the round robin participants would reject this grating as a 50 GHz ITU grating. The difference in the mean bandwidth, between the -0.5 and -3 dB criteria, is -11.5 GHz.

In some cases the participants data intervals were large enough to effect the determination of the bandwidth shown in Fig. 4. Participants C, E, and F all had coarse data sets. Participant D may not have normalized the reflectance to source power fluctuations. The -0.5 dB bandwidth is very sensitive to the shape of the ITU grating reflectance data.

The RGD linear slope of the chirped FBG was found by using a linear least squares fit to the RGD reflectance data, over the chirped grating's -3 dB bandwidth. From the round robin data the chirped FBG has a mean RGD linear slope of -6.81 ps/nm. Phase shift systems measure the RGD of all the fiber between the modulator and detector. Thus, to remove the system-fiber contribution to the FBG RGD linear slope the grating can be measured from both directions. The range on the mean of both directions of the RGD linear slope is 0.1 ps/nm with a σ of 0.04 ps/nm. If the system RGD is not removed, the range on the RGD linear slope is 1.1 ps/nm, a factor of ten worse.

Fig. 5 shows a portion of the residual RGD spectra taken with the NIST rf and low-coherence systems and with participant's A, B, E, and G systems. For most cases the ripple measurements agree, but wavelength accuracy, measurement uncertainty, and rf sideband averaging can lead to several ps differences [5]. The difference between the low-coherence system and rf phase shift systems is still being investigated, but no major differences have been observed [2]. The other round robin participant's RGD data could not be used to compare the ripple because of coarse wavelength steps. Fig. 5 illustrates the need for precision RGD ripple measurements, because over a 0.5 nm wavelength span the RGD changes rapidly from +5 to - 4 ps. Chirped gratings with larger RGD linear slopes will have larger RGD ripple amplitudes, increasing the need for more precision in RGD ripple measurements for WDM systems.

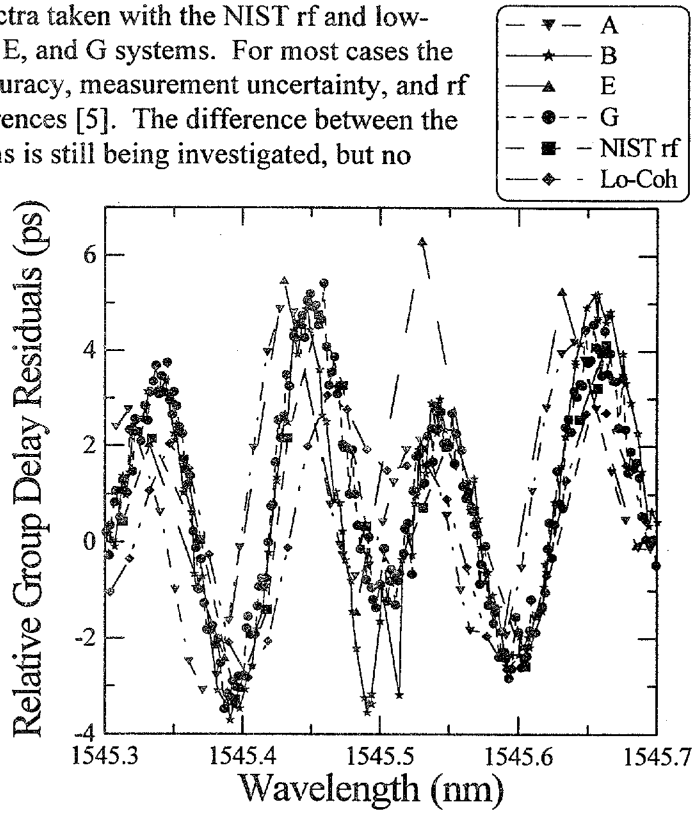

Figure 5 A portion of the RGD ripple from the chirped FBG as measured by various participants and NIST systems.

5. Conclusions

Metrology for WDM components, such as FBGs, must improve to meet the demands of current and future WDM networks. From this sampling of the round robin results we can draw the following conclusions. The source spectral purity is critical, ASE from diode sources must be substantially reduced. Wavelength accuracy <1 pm and <10 pm step sizes are necessary for bandwidth and RGD ripple measurements. Source spectral power fluctuation removal is necessary for bandwidth measurements. When using rf-phase-shift systems the best way to remove the system bias is by taking the mean of both directions on the grating. Stabilizing rf-phase-shift measurement systems and working at rf frequencies that do not average over >10 pm is necessary for RGD ripple measurements. Also, RGD resolution <1 ps will be required for most WDM components as data rates increase. RGD measurements with the low-coherence system compare well with phase-shift systems and may be preferred for rapid component evaluation.

6. References

[1] S. E. Mechels, J. B. Schlager, and D. L. Franzen, "Accurate Measurements of the Zero-Dispersion Wavelength in Optical Fibers," *J. Res. Natl. Inst. Stand. Technol.*, vol. 102, May-Jun. 1997, pp. 333-347.

[2] S. D. Dyer, K. B. Rochford, A. H. Rose, "Fast and accurate low-coherence interferometric measurements of fiber Bragg grating dispersion and reflectance," *Optics Express*, vol. 5, Nov. 1999, pp. 262-266.

[3] S. D. Dyer and K. B. Rochford, "Low-coherence interferometric measurements of fiber Bragg grating dispersion," *Electron. Lett.*, vol. 35, 1999, pp. 1485-1486.

[4] Generic Requirements for Fiber Optic Branching Components, GR-1209-CORE, Issue 2, Feb. 1998, Telcordia.

[5] R. M. Fortenberry, "Enhanced Wavelength Resolution Chromatic Dispersion Measurements using Fixed Sideband Technique," *Tech. Digest OFC 2000*, TuG8, Mar. 2000, pp. 107-109.